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A NON-TECHNICAL REPORT

on the

SECOND CORAL GABLES CONFERENCE

on

SYMMETRY PRINCIPLES AT HIGH ENERGY

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The experimental and theoretical efforts of the last ten years have demonstrated beyond any shadow of doubt that strongly interacting particles are bestowed by nature with properties not shared by particles interacting only through electromagnetic or gravitational fields. The physicists have named these fine articulations, as revealed by high energy experiments, "unitary symmetry".

These newly observed regularities have been proposed in addition to the symmetries contained in Albert Einstein's special theory of relativity discovered some sixty years ago. No contradictory experimental evidence has ever been found to the symmetries manifest in Einstein's theory. In principle, and in fact, all types of interactions, except gravitation, obey the laws of special relativity. However, as the range of an interaction gets smaller and smaller, additional symmetries besides those of Einsteinian origin, set in progressively with an increase of energy. Such is the state of things for heavy particles, called baryons and mesons or generically, hadrons. The complexities and intricacies involved in such states of matter came to be appreciated right after the discovery of the neutron by CHADWICK in Cavendish laboratory of Cambridge in 1932. Following this, WERNER HEISENBERG proposed that proton and neutron are actually two different states of the

same particle. Thus was introduced the concept of isotopic spin, which assigns two equal but opposite values of a quantum number to proton and neutron. This, together with NICHOLAS KEMMER's more formal introduction of charge independence of very short range forces between many particles, the SU_2 theory, actually contained the seeds of the concept of unitary symmetry.

For many years physicists have tended to use the isotopic spin concept on a semi-theoretical basis since the idea did not actually bring about a deeper understanding of the nature of nuclear forces between particles like proton, neutron and π-mesons. In the early 1950's there were only as few as 10 strongly interacting particles, and theorists were striving for a description of these states of matter in terms of the theory of HIDEKI YUKAWA, known as the discoverer of the "nuclear bond" or π-meson. Not until 1955 were any further symmetries suspected. At that time a surge of experimental activity began to produce a bevy of unusual particles, and, somewhat later, some very shortlived combinations of them, called "resonances". The problem of classifying these new entities led physicists to realize that a new theoretical crisis was in the making. MURRAY GELL-MANN and NISHIJIMA independently proposed a semi-theoretical scheme for bookkeeping and coding these new facts on particle physics. They observed that the electric charge of strongly interacting particles can be read

off by just adding together the two "internal" properties - isotopic spin and hypercharge - of the particles. The hypercharge was free invention, but one that agreed with experiment.

No basic or deeper understanding of the above theoretical gropings was in sight until in 1961 GELL-MANN and, independently, YUVAL NE'EMAN, came up with their "octet" or "eight-fold way" classification for these particles produced in abundance in most U.S. AEC (and European) laboratories at a cost of perhaps a dollar per particle. This was actually the beginning of the new era of unitary symmetry. It was symbolized by the adaptation of 19th century mathematics as the SU_3 theory of hadrons. The discovery of the Ω-particle last year at Brookhaven National Laboratory was regarded by most physicists as the crowning achievement of the SU_3 approach. However, despite these striking agreements some gaps were introduced by the succeeding experiments whereby a supermultiplet structure of the baryons had to be invoked. It appeared that ordinary spin and unitary symmetry were about to share a common property at very high energies: the forces between strongly interacting particles were independent of these symmetries. At high energies this led to a democratization of baryons into more populated classes, leaving the mesons still as noble as ever. Therefore, another rigorous and bold attempt was needed to vindicate these experimental facts by allowing a wedding between Euclidean (unitary symmetry) and non-Euclidean

(Einsteinian symmetry) features of particles.

A modest attempt of the above-mentioned kind was proposed in January 1964 at the first Coral Gables Conference on symmetry principles at high energy independently by BEHRAM KURŞUNOĞLU and by ASIM BARUT. The idea was attractive but these attempts failed. This was followed by a deluge of efforts by theorists all over the world. By August 1964 the mathematical SU_3 was doubled into SU_6 by FEZA GÜRSEY and RADICATI working at Brookhaven National Laboratory, and, independently, by BUNJI SAKITA in Argonne National Laboratory. The success of SU_6 was most impressive, but not quite in accord with the requirements of the special theory of relativity. The SU_6 theory had to confine all of its virtues to systems in state of rest. From August on all these endeavours have been raised to an even more intellectual and artistic platform. Most of the theorists have chosen a type of mathematical occupation "group theory" and adopted their own demi-gods. In the meantime, the preparations for the second Coral Gables Conference on the same topic were underway. Approximately 40 experts were invited to come to the University of Miami on January 20-22 to unload their widoms on this exciting subject matter.

Amongst the participants were such names as ROBERT OPPENHEIMER, ROBERT ADAIR, GREGORY BREIT, ROBERT MARSHAK, and MORTON HAMERMESH who chaired conference sessions. Following a

short expressive talk on symmetries by OPPENHEIMER, SALAM took the rostrum and unveiled, in his usual smooth but exciting style, the new symmetry group $\tilde{U}(12)$ (it is doubled again). This venture embraced both Euclidean and Einsteinian intricacies and complexities of particle behavior at high energy. It was a jump from the "eight-fold way" of GELL-MANN and NE'EMAN or 36, 56-fold ways of GÜRSEY, RADICATI and SAKITA, to the "364-fold way". That is, if you have found 364 baryons through the so-called atom smashers, then they can be populated without any inconsistency into a super-duper multiplet, sharing many like properties.

The reactions of the Conferees to his theory were mixed. In particular, ROBERT OPPENHEIMER did not show the expected enthusiasm. As a matter of fact, ABDUS SALAM appeared rather concerned about OPPENHEIMER's possible reaction to his theory even before his presentation. Later the same day a group theoretical approach on this very same topic was presented by KURŞUNOĞLU, based on a paper circulated among the Conferees some 3 months earlier. At the end of KURŞUNOĞLU's presentation SALAM himself was the first to recognize the identity of the two theories except for the notation. In fact, KURŞUNOĞLU has referred to his paper published 5 years earlier (Nuovo Cimento, 1960) containing wave equations predicting the new symmetry group with 144 types of motions. This particular fact was noticed only after SALAM discussed his identical version, independently, of course, of these particle wave equations. It must be emphasized that it is rather early to assess

the actual significance of these contributions for particle physics.

A different point of view and a more direct physical approach was taken by SUSOMO OKUBO and ROBERT MARSHAK. The size of their symmetries was of the same order of magnitude as the above theories but was based only on an Euclidean world. GEORGE SUDARSHAN gave a critical account of what has taken place during 1964 in the field of combining internal and space-time symmetries of particles into a unified symmetry pattern. There was no room to accommodate these super structures into a four-dimensional world. It thus ended all the frustrations of the physicists who pursued such unattainable goals.

It was the talk by GERSON GOLDHABER which pulled the theorists down to the realities of the experimental world. He was the only one who used the term SU_6 just once. The parade on the blackboard and in the slides of actual particles was a real treat to all the participants. It was clear that much remained to be understood and measured.

ROGER DASHEN had his feet on the ground when he presented a different way, the bootstrap way, of looking at symmetries. His approach has brought out a clear picture of why SU_3 has succeeded as far as it did. There were no pitfalls, the approach was based on dynamical considerations of actual interactions of particles at high energies. His

rather impressive presentation of the subject was a cause of the longest discussion of all the papers read at the meeting.

HARRY LIPKIN, the pioneer of good physics and good humor at high energies, has imparted considerable momentum to the discussions by bridging the usual gap between theory and experiment. As a matter of fact, LIPKIN is known as one of the foremost contributors to down-to-earth analysis of SU_3 theory. His discussions of the experimental and theoretical state of affairs in the field of symmetries were greatly appreciated by the Conferees since he focused his approach on less speculative, more factual aspects of symmetries.

LAURIE BROWN's talk was an example of the capability and endurance of a physicist who can get through the labyrinth of high order theoretical endeavour to really grasp the basic mechanisms that lie behind the decay of mesons. His enterprise and obvious success were greatly admired by the participants. It was a mammoth problem requiring the insight and patience of a real physicist.

YUVAL NE'EMAN, one of the authors of the "eightfold way", and an inventor of "Ottoman symmetries", gave a brief talk on his latest demi-god, another symmetry group not unlike to what was proposed in the earlier talks on this topic. He did not appear as enthusiastic about his speculations as did SALAM and KURŞUNOĞLU on their own proliferation of sub-nuclear particles.

There were so many overlapping ideas in all the group manipulations that it did not come as a surprise when the internal characteristics of BENJAMIN LEE's U(6) x U(6) proposition were proved to be of the same nature as those discussed previously. However, there were some intrinsic features of U(6) x U(6) theory that had not been shared by others.

High energy physicists have also injected some picturesque terms into their trade. The words "charm-number" related to electric charge, and "quarks" as smallest sub-nuclear units were the basis of an exceedingly clear discussion by YOICHIRO NAMBU. After all, quarks were the favorite way of the theorists for describing quantum properties of particles. Formally, quark is hoped to be the most symmetrical "triplet" input of nature into high energy events.

All this partly romantic and partly realistic picture created entirely by the theoretical members of the Conference was interrupted again by the factual world of experiments. A lucid and detailed presentation by SEYMOUR LINDENBAUM on the latest status of very high energy proton-proton, proton-meson and proton-other things scattering were, of course, the most powerful way of probing the very frontiers of high energy phenomena. One had the impression that all future surprises in particle physics were tightly packed into the smallest possible space which could only be unlocked by LINDENBAUM type of energies.

The conference reached its highest intellectual and abstract plateau in the personal charm and contents of LOUIS MICHEL's talk. Here was rigor and vigor at its best. One has to prove everything, no hand waving, no "sloppy proofs for sloppy theorems". If you believe in the group theoretical structure of particle physics, then do it in MICHEL's way.

JULIAN SCHWINGER, regarded as the connoisseur of elegant approach to physics, unfolded, in his usual absorbing way, the point of view of the field theory. Basically, his derivations and conclusions were not entirely different from the view points presented earlier.

The theory of weak interactions and unitary symmetry was treated in the two talks given by BERNARD d'ESPAGNAT and GEORGE ZWEIG. Both emphasized the important role of unitary symmetry in the choice of the correct leptonic and hadronic components of weak currents. In particular, ZWEIG used the compact group U(12) as point of departure for his discussions.

SAKITA made a brief statement on his calculation of baryon magnetic moments which agreed with SALAM's results.

This report would be incomplete without mentioning the brilliant summary of the conference given by NE'EMAN in his exquisitely inspired style. This was a Herculean task and part of the credit goes to us for requesting his services in this matter. We suspect that NE'EMAN's part may turn out to be the most widely read portion of the proceedings.

The conference was constantly enlivened by the incisive questioning and critical comments by BREIT, COLEMAN, HAMERMESH, MARSHAK, MESHKOV, ZUMINO, SELOVE, LIPKIN, NE'EMAN, OPPENHEIMER, SUDARSHAN, GOLDHABER, LEE and others.

To sum up one man's opinion of the impact of the Coral Gables Conference, I wish to posit the fact that these have provided uninterrupted contact during the conference and interaction amongst some of the outstanding experts in the field of high energy physics. It was this feature and the great interest of the participants that helped the second conference to essentially achieve the first phase of some of the goals set forth in last year's conference. It has played the role of a catalyst in the pursuit of the belief that experiment and theory could reach a more reasonable accord through the combination of internal and space-time symmetries. Despite the rudimentary nature of the original ideas presented at the first conference, the subsequent sagacious analyses by physicists throughout the world have culminated in the unfolding of SU_6 theory. However, the absence of relativistic elements in it could not allow physicists to give more than de facto recognition to SU_6. Between the summer of 1964 and the second Coral Gables Conference, the thrust for the inclusion of relativistic considerations reached a peak in the efforts of many theorists. The problem was at least partially unravelled

during the 1965 conference in the proposals of $\tilde{U}(12)(=L\tilde{U}(12))$, U(12), U(6) x U(6) and other theories and the corresponding compatible wave equations that were discussed.

The after dinner speech by ALVIN WEINBERG on "Science, Art, and Government" has clearly expressed this "triplet" as one of the most important foundation stone of our civilization.

We feel justified in continuing these meetings in the same style, and hope that they will lead to further progress in our attempts towards a unified structure in high energy physics.

Finally, the support by U.S. Atomic Energy Commission, U.S. Air Force Office of Scientific Research, National Science Foundation, National Aeronautics and Space Administration and, in particular, the presence of WAYNE GRUNER and Lt. DONALD LEHMAN at the conference were regarded as an indication of the agencies favourable disposition toward this meeting.

The technical account of the 1965 conference will appear shortly in the proceedings to be published by Freeman and Company Publishers, San Francisco.